Designation: ~~D6780/D6780M – 12~~ D6780/D6780M – 19

Standard Test ~~Method~~Methods for Water Content and Density of Soil In situ by Time Domain Reflectometry (TDR)[1]

This standard is issued under the fixed designation D6780/D6780M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method may be used to determine the water content of soils and the ~~in situ~~ density of soils ~~using a TDR apparatus.~~in place using Time Domain Reflectometry.

1.2 This test method applies to soils that have 30 % or less by weight of their particles retained on the 19.0-mm [¾-in.] sieve.

1.3 This test method is suitable for use as a means of acceptance for compacted fill or embankments.

1.4 This test method is not appropriate for frozen soils or soils at temperatures over 40°C [100°F] and may not be suitable for organic ~~and~~soils, highly plastic soils, or extremely dense soils.

1.5 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.5.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.[2]

1.6 Two alternative procedures are ~~provided.~~provided to determine the water content and the density of soil in situ:

1.6.1 *Procedure A* involves two tests in the field, an in situ test and a test in a mold containing material excavated from the in situ test location. The apparent dielectric constant is determined in both tests.

1.6.2 *Procedure B* involves only an in situ test by incorporating the first voltage drop and long term voltage (V_1 and V_f) in addition to the apparent dielectric constant. While the bulk electrical conductivity can be determined from these measurements, it is not needed for the determination of water content and density.

1.7 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. For additional information consult SI10.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate ~~safety~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))

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[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

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[2] "The Water Content and Density of Soil In situ by Time Domain Reflectometry apparatus and procedures are covered by a patent. If you are aware of an alternative(s) to the patented item, please attach to your ballot return a description of the alternatives. All suggestions will be considered by the committee."

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D6026 Practice for Using Significant Digits in Geotechnical Data
~~D6565~~E2877 ~~Test Method for Determination of Water (Moisture) Content of Soil by the Time-Domain Reflectometry (TDR) Method~~Guide for Digital Contact Thermometers ~~(Withdrawn 2014)~~
~~E1 Specification for ASTM Liquid-in-Glass Thermometers~~
SI10 ~~Standard for Use of the International System of Units (SI): The Modern Metric System~~American National Standard for Metric Practice

3. Terminology

3.1 *Definitions*—~~Refer to Terminology~~For definitions of ~~D653 for standard definitions of terms.~~common technical terms used in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *apparent dielectric constant, $K_{in\ situ}$,K_{mold},—[unitless], n—*the ability of a substance to store electrical energy in an electric field determined by the squared ratio of the velocity of light in air to the apparent velocity of electromagnetic wave propagation in the ~~soil measured by a TDR apparatus in situ and in the cylindrical mold, respectively.~~cylindrical mold probe and the multiple rod probe measured by a TDR apparatus.

3.2.2 *apparent length, l_a—[L], n—*~~on a plot of electromagnetic wave signal versus scaled distance measured by a TDR apparatus as shown in Fig. 1, it is~~ the horizontal distance between the point on the waveform due to the reflection from the surface of the soil where the probe is inserted into the soil to the point on the waveform due to the reflection from the end of the ~~probe.~~probe as shown in Fig. 1, a plot of electromagnetic wave signal versus scaled distance measured by a TDR apparatus.

3.2.3 *bulk electrical conductivity, EC_b—[SL^{-1}], n—*electrical conductivity is a measure of how well a material accommodates the transport of electric charge. ~~Its SI derived unit is Siemens per meter (S/m). As an electromagnetic wave propagates along TDR~~

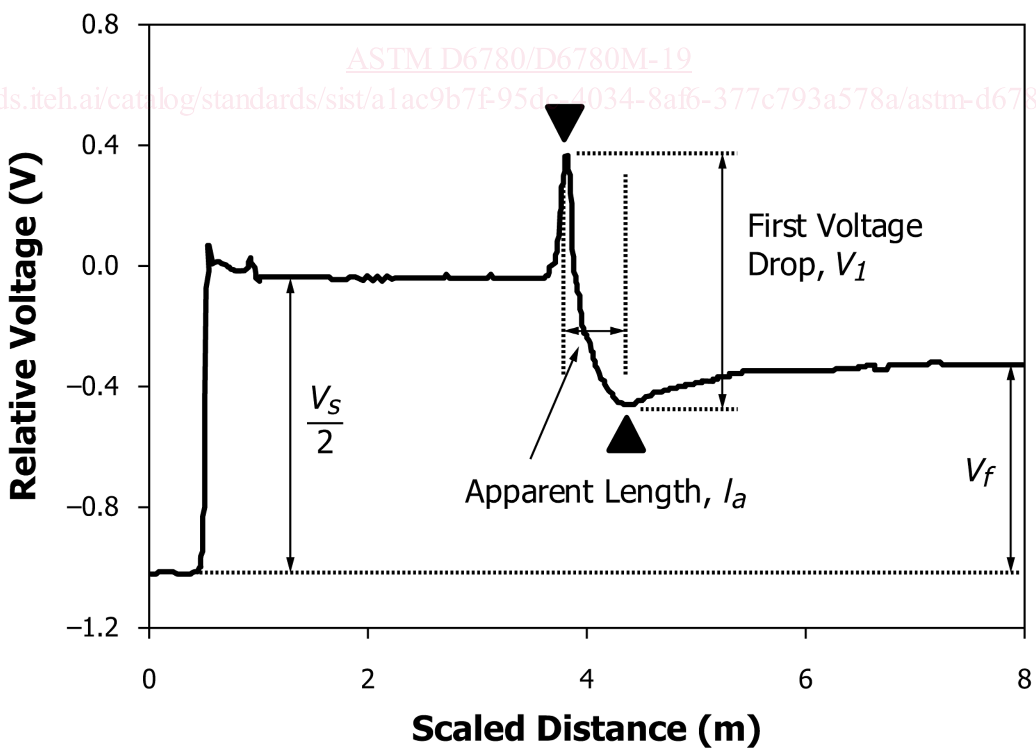


FIG. 1 Typical TDR Waveform for Soil Showing Measurements ~~to Obtain Apparent Dielectric Constant,~~ Apparent Length, ~~K~~l_a, ~~Bulk D.C. Electrical Conductivity,~~ Source Voltage, ~~EC~~V_{s}, First Voltage Drop, V_1, and Long Term Voltage, V_f to Obtain Apparent Dielectric Constant, K_a and Bulk D.C. Electrical Conductivity, EC_b.

~~probed buried in soil, the signal energy is attenuated in proportion to the electrical conductivity along the travel path. Determination of bulk electrical conductivity is illustrated in Fig. 1.~~

3.2.4 *coaxial head, CH*[4]—a device that forms a transition from the coaxial cable connected to the TDR apparatus to the Multiple Rod Probe or to a Cylindrical Mold Probe.

3.2.5 *cylindrical mold probe, CMP*[4]~~—~~*, n—*a probe formed by a cylindrical metal mold as the outer conductor having a non-metallic end plate, filled with compacted soil, and with an inner conductor consisting of a rod driven into the soil along the axis of the mold.

3.2.6 *first voltage drop,* V_1~~—~~ *[V], n—*~~it is~~ the vertical distance (voltage) between the point on the waveform due to the reflection from the surface of the soil where the probe is inserted into the soil to the point on the waveform due to the reflection from the end of the probe, as illustrated in Fig. 1.

3.2.7 *long term voltage,* V_f~~—~~ *[V], n—*the ~~long term~~ voltage asymptote as *scaled distance* becomes large as illustrated in Fig. 1.

3.2.8 *multiple rod probe, MRP*[4]~~—~~*, n—*a probe formed by driving four rods of equal length into the soil in a pattern where three of the rods define the outer conductor of a "coaxial cable" and one of the rods is the inner conductor.

3.2.9 *probe length,* ~~*L—*~~*for multiple rod probe,* $L_{in\ situ}$ *[L], n—*the length of the multiple rod TDR probe that is below the surface of the ~~soil.~~soil determined by total length of the rods minus the length exposed above the soil surface.

3.2.10 *probe length for cylindrical mold probe* L_{mold}*, [L], n—*length of the rod inserted into soil in the cylindrical mold probe that is below the surface of the soil in the mold determined by total length of the rod minus the length exposed above the soil surface.

3.2.11 *scaled distance,* ~~*l—*~~*l [L], n—*the ~~product of the~~ travel time of the electromagnetic wave in the probe converted to a distance by use of the velocity of light in ~~air and electromagnetic wave travel time in the soil divided by two.~~air. (This is a common output used by most commercially available TDR apparatus.)

3.2.12 *source voltage,* V_s~~—~~*, [V], n—*the source voltage ~~and~~ applied to the probe is equal to twice the step voltage generated read out by the ~~TDR.~~TDR apparatus.

3.2.13 *TDR internal resistance,* R_s~~—~~*, [Ω], n—*the internal resistance of the ~~TDR's~~ TDR apparatus' pulse generator (generally 50 ohms).

4. Summary of Test Method

4.1 *Procedure A*[5]—The dielectric constant of the soil in situ is determined using a multiple rod probe (*MRP*), a coaxial head (*CH*), and TDR apparatus. The soil at the location of the in situ measurement is then excavated and compacted in a mold. By measurement of the mass of the mold and soil and with the mass and volume of the mold known, the wet density of the soil in the mold is determined. A rod driven into the soil along the axis of the mold creates a cylindrical mold probe (*CMP*). Using the same coaxial head (*CH*), an adapter ring, and the TDR apparatus the dielectric constant of the soil in the mold is measured. The water content of the soil in the mold is determined using a correlation between the dielectric constant, moisture content and soil density. The correlation requires two constants that are somewhat soil specific. It is assumed that the water content of the soil in situ is the same as the water content in the mold. The dry density of the soil in situ is determined from the density of the soil in the mold and the dielectric constants measured in the mold and in situ.

4.2 *Procedure B*[5]—The apparent dielectric constant of the soil in situ, first voltage drop and long term voltage (V_1 and V_f) are determined using a multiple rod probe (*MRP*), a coaxial head (*CH*), and TDR apparatus. The water content and density of the soil in situ are determined from the measured apparent dielectric constant, V_1,V_f and five constants. The five soil constants are soil and in situ pore fluid dependent. The five soil constants are determined in conjunction with laboratory compaction procedures using specified compaction procedures, for example, Test Method D698, and by taking measurements of the apparent dielectric constant, V_1 and V_f for each compaction point.

5. Significance and Use

5.1 This test method can be used to determine the density and water content of naturally occurring soils and of soils placed during the construction of earth embankments, road fills, and structural backfills.

5.2 Time domain reflectometry (TDR) measures the apparent dielectric constant (Procedure A) and the apparent dielectric constant, first voltage drop and long term voltage (V_1 and V_f) (Procedure B) of soil. The apparent dielectric constant is affected

[4] The apparatus is covered by patents. Interested parties are invited to submit information regarding the identification of alternative(s) to this patented item to the ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[5] The apparatus and procedures are covered by patents and pending patents. Interested parties are invited to submit information regarding the identification of alternative(s) to these patented items to the ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

significantly by the water content and density of soil, and to a lesser extent by the chemical composition of soil and pore water, and by temperature. The first voltage drop and long term voltage (V_1 and V_f) are affected significantly by the water content, density, and the chemical composition of the in situ pore water, and to a lesser extent the chemical composition of the soil solids. This test method measures the gravimetric water content and makes use of a different relationship between the electrical properties and water content from Test Method D6565 which measures the volumetric water content.

5.3 Soil and pore water characteristics are accounted for in Procedure A with two calibration constants and for Procedure B with five calibration constants. The two soil constants for Procedure A are determined for a given soil by performing compaction tests in a special mold as described in Annex A2. The five soil constants for Procedure B are determined in conjunction with compaction testing in accordance with specified compaction procedures, for example, Test Method D698 as described in Annex A3. Both Procedures A and B use Test Method D2216 to determine the water contents.

5.4 When following Procedure A, the water content is the average value over the length of the cylindrical mold and the density is the average value over the length of the multiple-rod probe embedded in the soil. When following Procedure B, the water content and density is the average values over the length of the multiple-rod embedded in the soil.

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Interferences

6.1 Quality and accuracy of the test results significantly depend on soil having contact with the inner conductor of the probes. To assist this, when installing the rods of the *MRP*, the rod that forms the inner conductor must be the last rod installed. If in the installation process, the rod hits upon a large particle that causes it to drift from vertical alignment, all rods should be removed and the test conducted in a new location at least 0.2-m [8-in.] from the previous test location.

6.2 The quality of the signal read by the TDR apparatus depends on having clean contacts between the *CH* and the *MRP* and the *CMP*. The contacting surfaces should be wiped with a clean cloth prior to placing the *CH* on the *MRP* and the *CMP*. Once placed, observe the signal on the TDR apparatus. If the characteristic signal is not present, the *CH* may have to be slightly rotated about its axis to make better contact.

6.3 This test method only applies to non-frozen soil. is not appropriate for frozen soils or soils at temperatures over approximately 40 °C [100 °F]. The apparent dielectric constant is slightly temperature dependent for soils and depends on soil type. For soil temperatures between 15°C15 °C and 25°C [59°F25 °C [59 °F and 77°F],77 °F], no temperature corrections are needed for most soils. A simple temperature adjustment for water content determination is part of the test method.

6.4 This test method may not be applicable in some very dense soils (dry density > 95 % of D1557 (modified effort compaction)) due to disturbance in driving the spikes into the soil unless holes for spikes are predrilled with a carbide-tipped masonry bit with diameter approximately 80 % of the spike.

6.5 This test method may not be applicable in some organic soils or highly plastic clays, for example, Liquid Limit >50 % due to attenuation of the electrical signal from the high bulk electrical conductivity frequently associated with such soils.

7. Apparatus

7.1 *TDR Apparatus,* a Metallic Time Domain Reflectometer with a scaled length resolution of at least 2.4-mm [0.10-in.] (this corresponds approximately to a time between data points less than or equal to sixteen picoseconds (16×10^{-12} s). A portable computer with a communication port to the TDR is suggested for controlling the apparatus, acquiring and saving the data, and for making the calculations as the test proceeds.

7.2 *Multiple Rod Probe (MRP)*[4] with Coaxial Head (CH)[34]

7.2.1 The *MRP* consists of four common steel spikes, typically 250-mm [10-in.] in length and uniform diameters of 9.5-mm [3⁄8-in.]. (Other length spikes, but with the same diameter, may be used but in no case should they have lengths less than 150-mm [6-in.]. For lengths longer than 250-mm [10-in.], drift in the alignment of the spikes and loss of reflected signal from the end of the *MRP* may occur.)

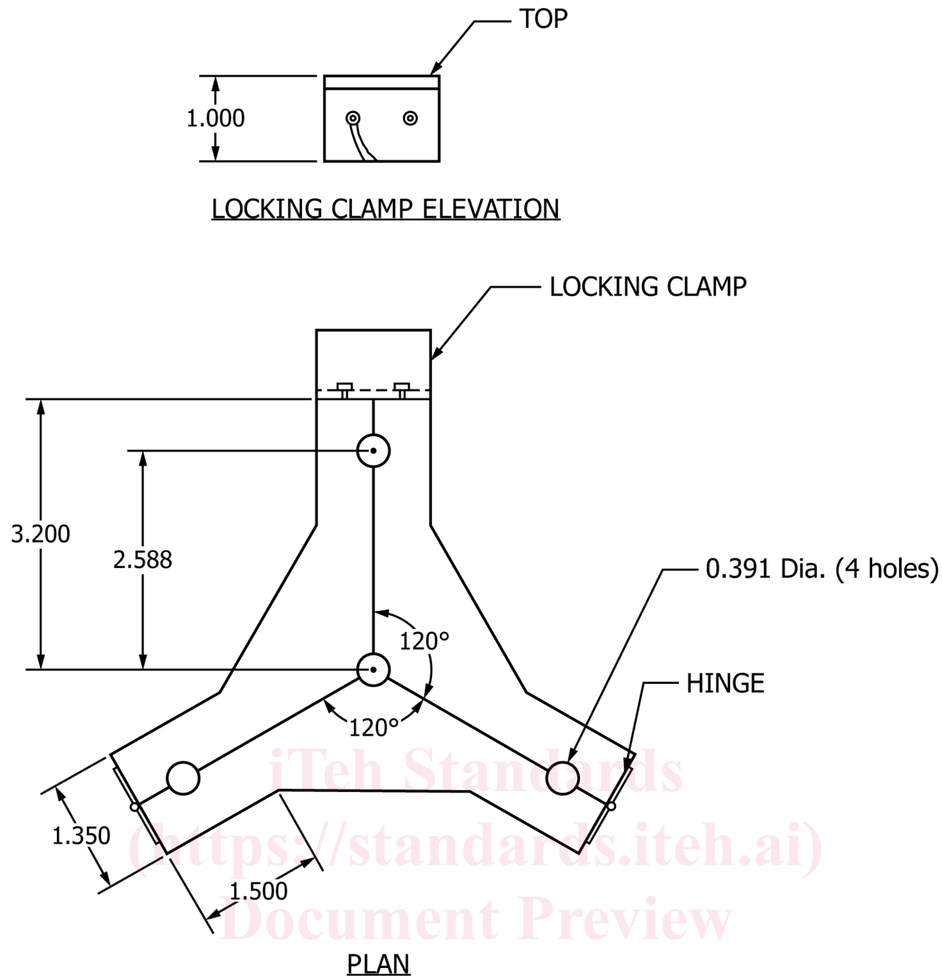
7.2.2 A *MRP* guide template (see Fig. 2 as an example) is used to guide the spikes as they are driven into the soil. The template must allow for its removal after the spikes are driven and before a TDR measurement is made. (The radius from the central spike to the outer spikes must be within the range of 5 to 7.5 times the diameter of the central spike.)

7.2.3 The Coaxial Head (*CH*)[4] (see Fig. 3) as an example) forms a transition from the coaxial cable coming from the TDR apparatus to the *MRP*.

7.3 *Cylindrical Mold Probe (CMP)*[4], the *CMP* consists of a cylindrical mold, a guide template, a central rod, and a ring collar. Details for these items are shown in Fig. 4.

7.3.1 Volume of 943.0 ± 14 cm^3 [0.0333 ± 0.0005 ft^3].

7.3.2 The central rod in this example probe is a stainless steel rod with a diameter of 8.0-mm [5⁄16-in.] and a length of 264-mm [10.4-in.] in length.



NOTE 1—All dimensions are in inches. See Table 1 for tolerances and metric equivalents.

FIG. 2 Example of a *MRP* Guide Template

TABLE 1 ~~Metric~~SI Equivalents for Dimensions in Fig. 2

[in.]	Tol. [in.]	mm	Tol. mm
0.391	± 0.002	10.00	± 0.05
1.000	± 0.005	25.00	± 0.15
1.350	± 0.015	34.30	± 0.40
1.500	± 0.015	38.00	± 0.40
2.588	± 0.005	65.70	± 0.13
3.200	± 0.020	80.00	± 0.50

7.4 *Balances or Scales,* meeting Specification GP10 of Specification D4753 to determine the mass of the soil and the cylindrical mold. A battery-operated balance or scale having a minimum capacity of 10 kg [25 lbm] is suitable when an apparatus with the dimension given in Fig. 3 is used.

7.5 *Driving Tools,* a brass-headed hammer for driving spikes for the *MRP* and the central rod into the cylindrical mold. A resin-headed hammer also may be used for driving the central rod into the cylindrical mold. (Use of these hammers prevents peening of the driving end of the steel rods from repeated use.)

7.6 *Tamping Rod,* an aluminum rod with flat ends, a diameter of 37-mm [1.5-in.], and a length of approximately 380-mm [15-in.]. Other tamping devices which provide a relatively uniformly compacted specimen also may be used.

7.7 *Thermometric Device,* 0 to 50 °C range, 0.5 °C graduations, conforming to requirements of Specification ~~E1~~E2877 or a temperature measuring device with equal or better accuracy.

7.8 *Vernier or Dial Caliper,* having a measuring range of at least 0 to 250-mm [0 to 10-in.] and readable to at least 0.02-mm [0.001-in.].

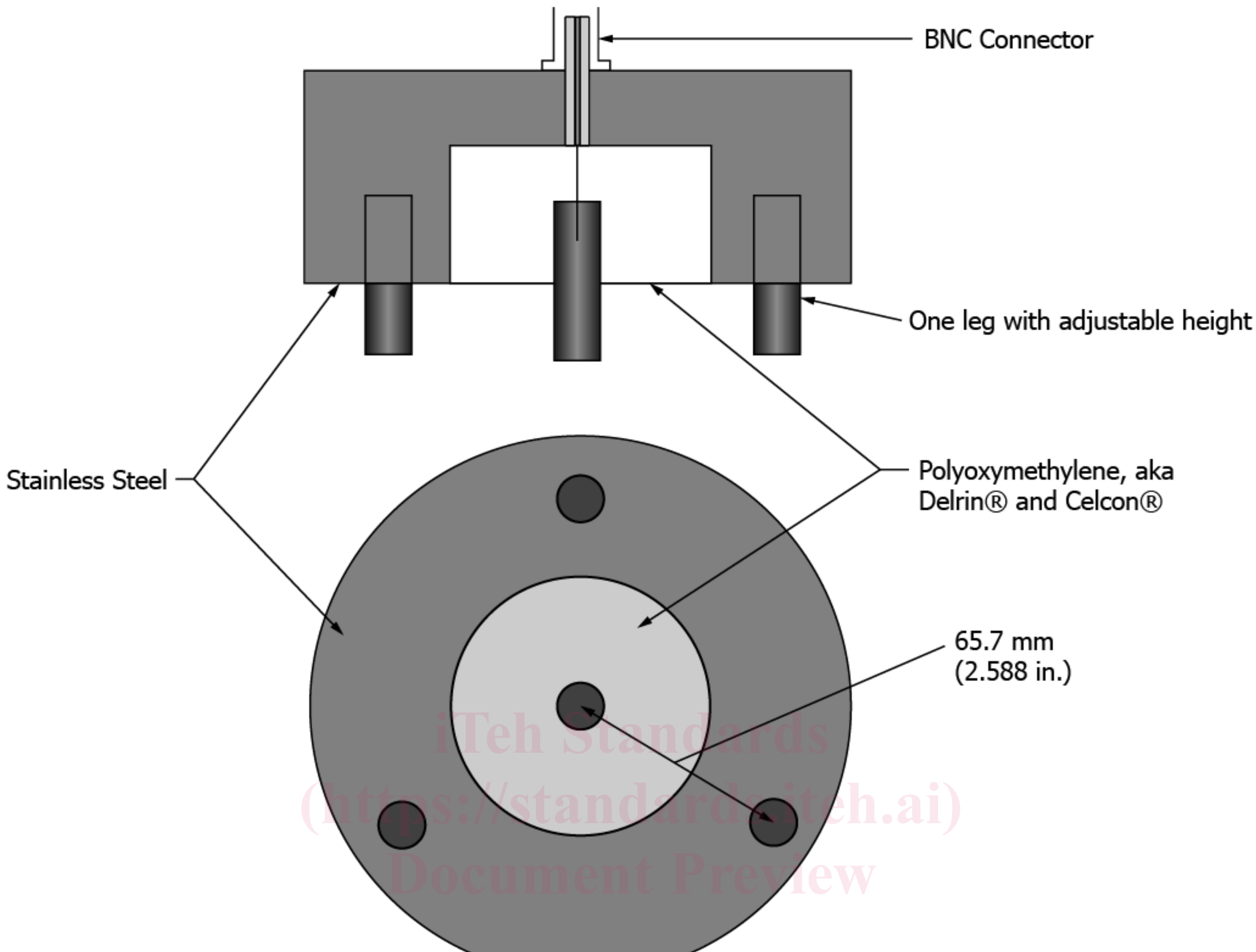


FIG. 3 Example of a Coaxial Head (*CH*)

7.9 *Miscellaneous Tools,* a battery-powered hand drill with a spare battery and charger and with a 25-mm [1-in.] diameter auger bit (alternatively, a small pick will work), straight edge for smoothing the surface of the soil for the in situ test and for smoothing the surface of the soil in the cylindrical mold, pliers for removing the spikes and central rod, small scoop or spoon for removal of the loosened soil and for placement in the cylindrical mold, cloth for cleaning the contact area of the and a brush for removing excess soil from around the base of the cylindrical mold prior to determining its mass.

8. Preparation of Apparatus

8.1 Charge or replace, as appropriate batteries in the TDR apparatus, the hand drill, and the balance.

9. Calibration and Standardization

9.1 Determine the average length of the spikes that will penetrate into the soil surface in the in situ test, $L_{in\ situ}$, m [in.], by inserting each spike into the *MRP* guide template and measuring the length that each spike protrudes from the template when fully inserted. All measured lengths should be equal within 0.5-mm [0.020-in.].

9.2 Determine the volume of the cylindrical mold, V_{mold}, m^3 [$in.^3$], in accordance with Annex A1.

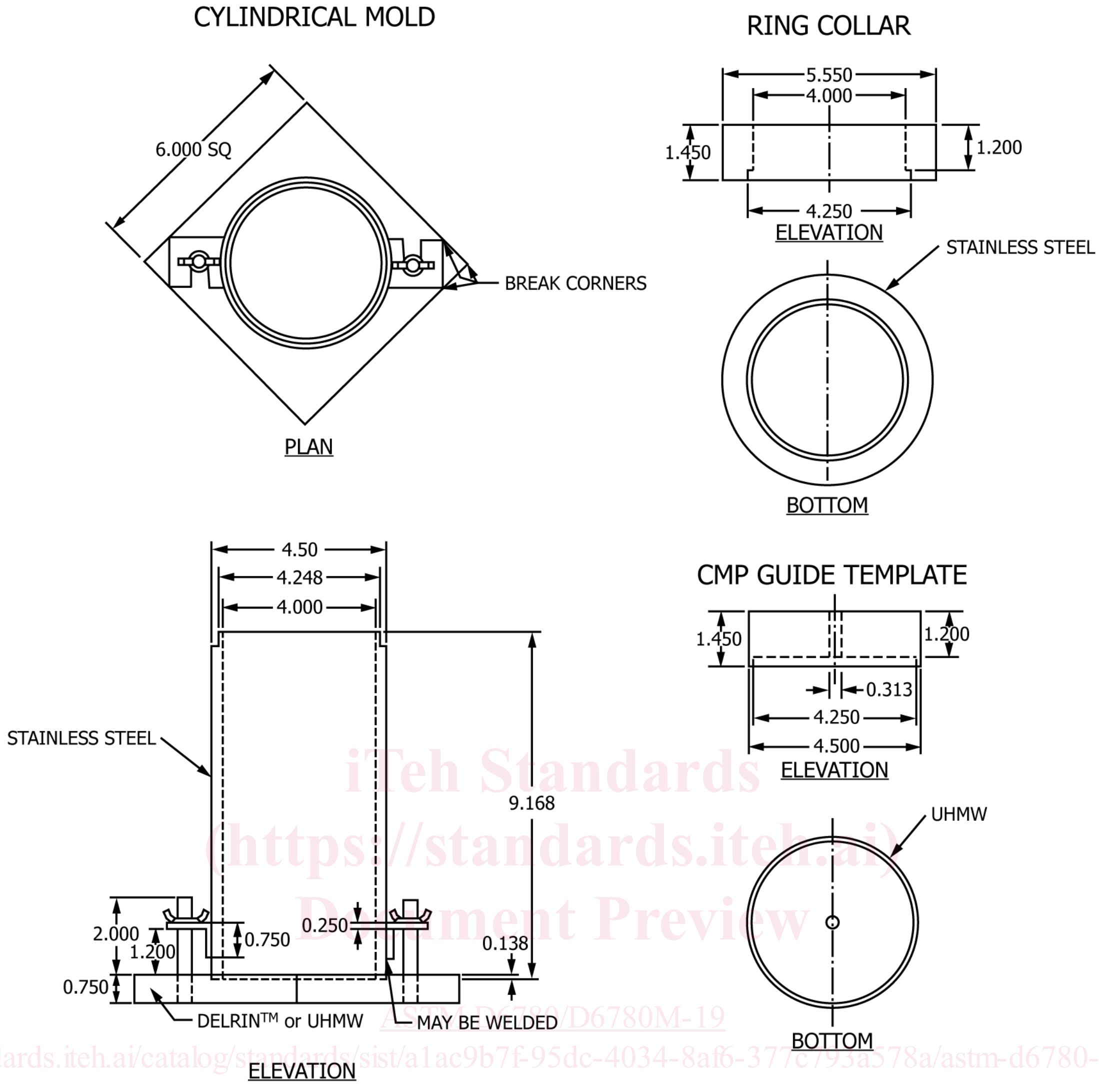
9.3 Determine the mass of the empty and clean cylindrical mold including the base, but without the ring collar, M_2, kg [lbf], by placing on a calibrated balance.

9.4 Determine the length of the central rod for insertion into the compaction mold, $L_{central\ rod}$, m [in.].

9.5 *Calibration Constants:*

9.5.1 *Procedure A*—Determine the values of *a* and *b* for the soils to be tested in the field by procedures in Annex A2.

9.5.2 *Procedure B*—Determine the values *a*,*b*,*c*,*d*, and *f* for the soils to be tested in the field by procedures in Annex A3.



NOTE 1—All dimensions are in inches. See Table 2 for tolerances and metric equivalents.

FIG. 4 Example of a Cylindrical Mold, Ring Collar, and Guide Template

TABLE 2 ~~Metric~~SI Equivalents for Dimensions in Fig. 4

[in.]	Tol. [in.]	mm	Tol. mm
0.138	± 0.005	3.50	± 0.13
0.250	± 0.005	6.30	± 0.13
0.313	+ 0.002, − 0.000	7.88	+ 0.05, − 0.00
0.750	± 0.010	18.90	± 0.25
1.000	± 0.010	25.00	± 0.25
1.200	± 0.002	30.24	± 0.05
1.450	± 0.005	36.54	± 0.13
2.000	± 0.020	50.00	± 0.50
4.000	± 0.016	100.00	± 0.40
4.248	+ 0.000, − 0.003	107.90	+ 0.00, − 0.08
4.250	+ 0.003, − 0.000	107.95	+ 0.08, −0.00
4.500	± 0.020	115.00	± 0.50
5.500	± 0.020	140.00	± 0.50
6.000	± 0.020	150.00	± 0.50
9.168	± 0.020	231.00	± 0.50

10. Procedure for In situ Testing

10.1 The following is applicable for Procedures A and B:

10.1.1 Prepare the surface at the test location so that it is plane and level.

10.1.2 Seat the *MRP* guide template on the plane surface.

10.1.3 Drive the outer spikes through the guide holes so that the bottom surfaces of the spike heads touch the template. Drive the central spike last. (See Fig. 5.)

10.1.4 Remove the template as shown in Fig. 6. Check that all spikes are driven properly without any air gap around the spikes where they penetrate the soil.

10.1.5 Connect the coaxial cable to the *CH* and the TDR device. Turn on the device.

10.1.6 Wipe the top surfaces of the spike heads and ends of the studs on the *CH* and place the *CH* on the spikes, centering the *CH* on the heads of all the spikes as shown in Fig. 7.

10.1.7 Activate a TDR measurement and, observe the signal on the TDR apparatus. If the characteristic signal is not present (see Fig. 1), the *CH* may have to be slightly rotated about its axis to make better contact.

10.1.8 Determine and record the apparent length, $l_{in\ situ}$, m [in.] with the TDR equipment.[6,7]

10.1.9 When following Procedure B, determine and record the source voltage, V_s, the first voltage drop, V_1, and the long term voltage, V_f, from the TDR waveform[8] as illustrated in Fig. 1.

10.1.10 Remove the spikes.

10.2 For Procedure A, do the following:

10.2.1 Measure the apparent length in the cylindrical mold.

10.2.2 Assemble and secure the cylindrical mold to the base plate and attach the ring collar.

10.2.3 With the use of the power drill or other suitable digging implement, excavate the soil from the between the holes left by the outer rods of the *MRP* and to a depth corresponding to the rod penetration and place the soil into the cylindrical mold in 6 uniform lifts applying 10 blows per lift using the ~~aluminum tamping rod or other suitable tamping device.~~tamping rod. Soil should be taken uniformly over the entire depth of in situ measurement and placed directly and quickly into the cylindrical mold to minimize moisture loss. Remove the ring collar and strike the surface level with the straight edge after compaction. Remove any spilled soil from around the exterior of the base plate with the brush.

10.2.4 Make sure the balance is leveled, measure and record the mass of the soil-filled cylindrical mold including the base plate, M_1, kg [lb].

10.2.5 Clean the shoulder at the top of the mold and mount the cylindrical mold guide template on to the cylindrical mold.

10.2.6 Using the brass-headed or resin-headed hammer, drive the central rod through the guide hole into the soil until the top of rod is flush with the template.

10.2.7 Remove the guide template from the cylindrical mold.

10.2.8 Determine and record the length of the central rod above the soil surface, $L_{rod\ exposed}$, m [in.].

10.2.9 Clean the shoulder at the top of the mold and place the ring collar on the cylindrical mold. Rotate the ring back and forth on the mold to facilitate good electrical contact.

10.2.10 Wipe the top surface of the ring collar, the central rod and the ends of studs of the *CH* and then place the *CH* on the ring collar, centering the central stud on the central rod as shown in Fig. 8.

10.2.11 Activate a TDR measurement and, observe the signal on the TDR apparatus. If the characteristic signal is not present (See Fig. 1), the CH may have to be slightly rotated about its axis to make better contact.

10.2.12 Determine and record the apparent length, l_{mold}, m, with the TDR device.[6]

10.2.13 Remove the central rod from the mold.

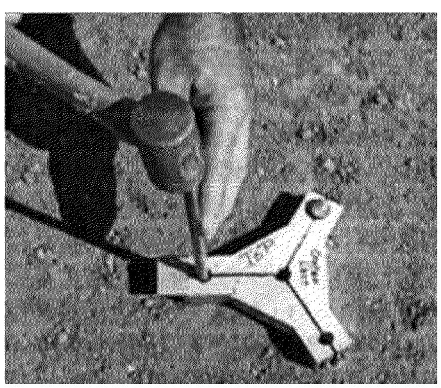


FIG. 5 Driving Spikes through Template

[6] Automated procedures for doing this are usually contained in a program on the portable computer. Algorithms for various procedures are discussed by Baker and Allmaras (1990) (**1**[7]), Feng et al. (1998) (**2**), Heimovaara and Bouten (1990) (**3**), and Wraith and Or (1999) (**4**).

[7] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[8] Background for making these measurements is provided by Yu and Drnevich (2004) (**5**) and ~~Jung (2011)~~ Jung, et al. (2013) (**6**).

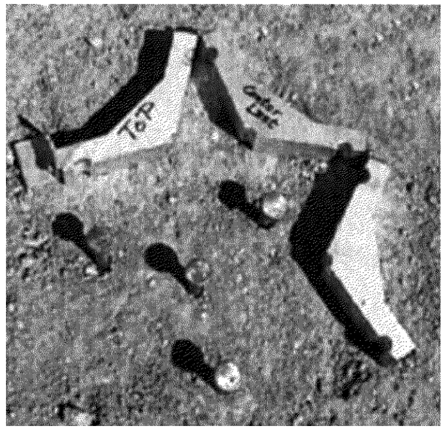


FIG. 6 Removal of Template after Driving Spikes

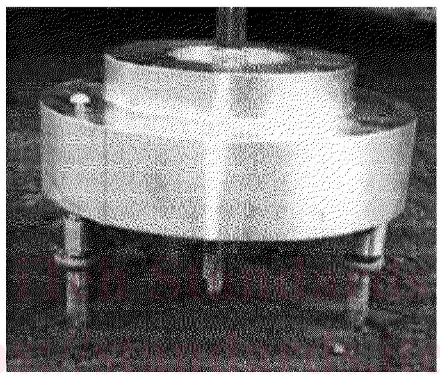


FIG. 7 Placement of Coaxial Head on Spikes

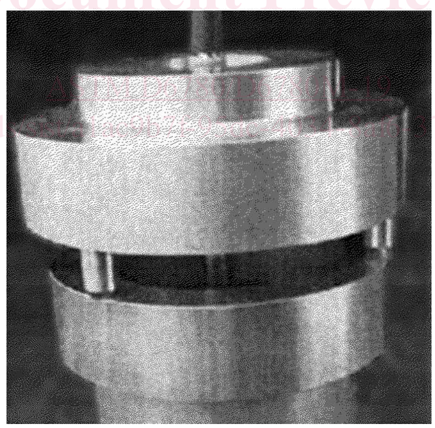


FIG. 8 Coaxial Head on Ring Collar

10.2.14 If the soil is a cohesive soil and if the temperature of the soil is estimated to be outside the range of 15 to 25°C [59 to 77°F], insert a metal thermometer into the hole created by the central rod, wait until the temperature stabilizes, and record the temperature, ~~°C.~~°C [°F].

10.2.15 Remove the soil from the cylindrical mold.

11. Calculation or Interpretation of Results

11.1 Calculate the apparent dielectric constant of the soil in ~~place~~situ as follows:

$$K_{in\ situ} = \left[\frac{(l_a)_{in\ situ}}{L_{in\ situ}} \right]^2 \quad (1)$$

where:

$K_{in\ situ}$ = apparent dielectric constant of the soil in situ,

$(l_a)_{in\ situ}$ = measured apparent length in situ, m [in.], and
$L_{in\ situ}$ = length below the surface of the soil of the spikes inserted into the soil, m [in.].

11.2 *Procedure A:*

11.2.1 Calculate the dielectric constant of the soil in the mold as follows:

$$K_{mold} = \left[\frac{(l_a)_{mold}}{L_{mold}}\right]^2 \quad (2)$$

where:

K_{mold} = apparent dielectric constant of soil in the mold,
$(l_a)_{mold}$ = measured apparent length in the mold, m [in.], and
~~L_{mold} = length of the rod inserted into the soil in the mold, m [in.]~~
L_{mold} = length of the rod inserted into the soil in the mold below the surface of the soil, m [in.]
= $L_{central\ rod} - L_{rod\ exposed}$

11.2.2 Calculate the wet density of the soil in mold as follows:

$$\rho_{t,mold} = \frac{M_1 - M_2}{V_{mold}} \quad (3)$$

where:

$\rho_{t,mold}$ = wet density of the soil in the mold, kg/m^3 [lbf/ft^3],
M_1 = mass of the soil-filled mold, and base plate, kg [lbf],
M_2 = mass of the empty mold and base plate, kg [lbf],
V_{mold} = volume of the mold, m^3 [ft^3].

11.2.3 Calculate the apparent dielectric constant of the soil in the mold at 20 °C from:

$$K_{mold,20\,°C} = K_{mold,T\,°C} \times TCF_K \quad (4)$$

where:

TCF_K = Temperature Correction Factor,[9]
= 0.97 + 0.0015T °C for cohesionless soils, 4 °C ≤T °C ≤ 40 °C, and
= 1.04 – 0.0019 T °C for cohesive soils, 4 °C ≤ T °C ≤ 40 °C.

11.2.4 Calculate the water content of the soil in the mold and in place as follows:

$$w_{in\ situ} = w_{mold} = \frac{\sqrt{K_{mold,20\,°C}} - \dfrac{a\rho_{t,mold}}{\rho_w}}{\dfrac{b\rho_{t,mold}}{\rho_w} - \sqrt{K_{mold,20\,°C}}} \times 100 \quad (5)$$

where:

w_{mold} = water content of the soil in the mold, %,
$w_{in\ situ}$ = water content of the soil in situ, %,
~~ρ_w = density of water = 1000 kg/m^3 [62.4 lbf/ft^3],~~
ρ_w = density of water ≈ 1000 kg/m^3 [62.4 lbf/ft^3] sufficiently accurate for these tests,
~~a = calibration constant, (see Annex A2), and~~
A = calibration constant, (see Annex A2), and
~~b = calibration constant, (see Annex A2).~~
B = calibration constant, (see Annex A2).

11.2.5 Correct the apparent dielectric constant calculated in 11.1 to $K_{in\ situ,\ 20°C}$ from:

$$K_{in\ situ,20\,°C} = K_{in\ situ,T°} \times TCF_K \quad (6)$$

11.2.6 Calculate the in situ dry density of the soil as follows:

$$\rho_{d,in\ situ} = \frac{\sqrt{K_{in\ situ,20°C}}}{\sqrt{K_{mold,\ 20\,°C}}} \times \frac{\rho_{t,mold}}{1 + \dfrac{w_{mold}}{100}} \quad (7)$$

where:

$\rho_{d,\ in\ situ}$ = dry density of the soil in situ, kg/m^3 [lbf/ft^3].

11.3 *Procedure B:*

[9] See Dallinger (2006) (7) for discussion of these values.